AD-757 629

A STOCHASTIC NETWORK TO MODEL AIR CARGO TERMINALS

Howard A. Porte, et al

Army Construction Engineering Research Laboratory
Champaign, Illinois

February 1973

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Construction Engineering Research Laboratory P. O. Box 4005 Champaign, Illinois 61820	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

A STOCHASTIC NETWORK TO MODEL AIR CARGO TERMINALS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Manuscript

5. AUTHOR(S) (First name, middle initial, last name)

H. A. Porte, W. W. Happ, C. T. Lee, L. P. McNamee

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1973	18	5

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Manuscript A-7
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES Copies of this report are obtainable from National Technical Information Service, Springfield, Virginia 22151	12. SPONSORING MILITARY ACTIVITY Department of the Army

13. ABSTRACT

Cargo flow through an air cargo terminal is modeled as an activity network by utilizing: (a) deterministic and probabilistic decision-making elements as nodes, (b) activities or branches which relate the nodes and whose characteristics determine the magnitude and delay of commodity flow, and (c) a set of statistical monitors to count events and to perform statistical evaluations at strategic points of the network.

Bottlenecks of the material handling operation of an air cargo terminal are investigated by the stochastic network method of GERT IIIQ. The relationship of the GERTS IIIQ network model to construction specification is discussed. Operations bottlenecks are identified and corrected through modification of facility constraints. (M)

14. KEY WORDS

air cargo, simulation model, materials handling

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED

Security Classification

AD-757629

TECHNICAL MANUSCRIPT A-7

A STOCHASTIC NETWORK TO MODEL AIR CARGO TERMINALS

by

H. A. Porte
W. W. Happ
C. T. Lee
L. P. McNamee

February 1973

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
P.O. Box 4005
Champaign, Illinois 61820

FOREWORD

This paper was presented by Dr. H. A. Porte at the Army Science Conference held in West Point, New York, 20 - 23 June 1972.

The investigation was supported by the Office of the Chief of Engineers and was performed at the Construction Engineering Research Laboratory (CERL) and at the University of California at Los Angeles (UCLA).

Dr. H. A. Porte is a research scientist in the Electromechanical and Environmental Systems Division, CERL; Dr. W. W. Happ is Dean, School of Engineering, Sacramento State University, Sacramento, California; Mr. C. T. Lee is a systems analyst at Litton Data Systems Division, Woodland Hills, California; Dr. L. P. McNamee is Associate Professor, Computer Science Department, UCLA.

Preceding page blank

CONTENTS

A STOCHASTIC NETWORK TO MODEL AIR CARGO TERMINALS

by

H. A. Porte
W. W. Happ
C. T. Lee
L. P. McNamee

1.0 INTRODUCTION

In recent years design approaches to aircargo terminal operations had to be reexamined in order to cope with the vast increases in the cargo handling requirements due to the introduction of jumbo jets. Although a new cargo handling system proposed by Dortech [1] would seem to handle the large cargo commitments, virtually no evaluation of its functional capabilities had been verified by actual design or by in depth computer simulation studies.

Relevant computer studies include: the simulation of aircargo input/output cargo flow patterns [2], and the development of a GERTS IIIQ simulation model of a Dortech type aircargo facility.

In this paper an in depth parameter study of the Dortech approach to aircargo handling is presented by means of a GERTS IIIQ simulation model. All parameter variations are related to construction design considerations. The next section describes the development of the GERTS IIIQ simulation model. The remainder of the paper discusses the simulation studies and their interpretation.

2.0 A GERT IIIQ SIMULATION MODEL OF A DORTECH TYPE FACILITY

2.1 Requirements For Air Cargo Facilities. In order to model air cargo facilities it is necessary to identify the appropriate functional operations in the terminal, including the pertinent parameters, and to establish relationships between these operations.

The major air freight terminal operations are: (1) Receive and ship freight by land carriers, such as trucks and trains, and by jumbo jets such as the C-5A and C-141. (2) Inspect, document, and sort cargo according to destination. (3) Transfer cargo within the terminal for processing. (4) Provide storage for aggregation of cargo for future shipments. (5) Breakdown and buildup of cargo

into manageable units for reshipping. (6) Handle special and/or high priority freight

To carry out all of these functions it is necessary to provide a coordinated operations involving manpower, both moveable and stationary material handling equipment, and control. The important operational parameters are: (1) The Tonnage-volume of the cargo to be handled at each station, (2) The speed at which each operation is conducted, and (3) The control of branching between stations.

The basic considerations in dealing with the volume of cargo at stations and with the speed of processing it are: (1) The method of unitization, (2) Speed and width of conveyors, (3) The number, speed and payload of moveable material handling equipment, (4) Speed and space required by heavy moving equipment, (5) Storing and retrieval speeds, and (6) Areas provided for pallet buildup and breakdown.

Recently Dortech introduced a new approach to air cargo handling which utilizes towline carts for station to station transfer within the terminal building, and stacker bins for aggregation of cargo for future shipments.

The towline carts are 8 ft. long, 4 ft. wide, and 5 ft. high with an average load capacity of 1200 lbs. Transportation of these carts is by means of a towline built into the terminal floor. The destination is determined by selecting a particular towpin which is programmed for transportation to a specific station. The empty cars are returned in a similar manner to the loading docks or to other stations.

Cargo, along with its towline cart, can be randomly stored in stacker bins by cranes which can move both laterally and vertically. The stacker bins are located in a structure 150 ft. wide and 40 ft. high. Cargo can easily be retrieved upon command.

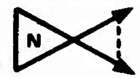
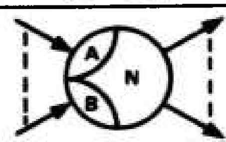
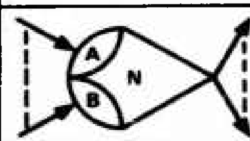
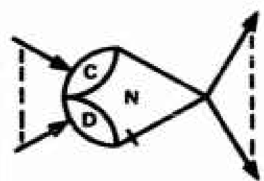
The towline operation requires less equipment space to transfer cargo between stations and sort cargo than a conveyor system. However it must be kept in mind that the reduction in space is reflected by the addition of the stacker bin storage area.

2.2 The Dortech Simulation Model. A GERTS IIIQ simulation model of a Dortech type facility is shown in Figure 2.1. The GERTS IIIQ symbols are defined in Table 2.1. (A more detailed description of GERTS IIIQ can be obtained in [4].) Arriving truck freight is simulated by source node 2 and event node 3; arriving airplanes by source node 50 and event node 51. Truck and plane departures are represented by sink nodes 45 and 90, respectively. Trucks are unloaded according to one of the following cargo types; multipallets, cartable, noncartable/oversize, pallet, and priority/special handling. Both C-5A and C-141 aircraft are accommodated. The activities associated with all of the branches are given on the diagram.

Some of the assumptions made to simplify the model are: (1) Only freight which can be palletized is handled inside the terminal. (2) Trucks carry 15 ton loads but are unloaded or loaded in 3 ton groups. (3) Airplanes arrive and depart with 75 tons for a C-5A and 27 tons for a C-141. (4) Three tons of unloaded truck cargo is

TABLE 2.1

GERT IIIQ NODE CAPABILITIES

PROGRAMS	NODE FUNCTION	DETERMINISTIC SYMBOL	PROBABILISTIC SYMBOL	PARAMETERS
Basic to Gert III	Source			A = No. of times activities incident to the node must be realized for node to be realized B = No. of times activities incident to the node must be realized after the first time the node is realized to repeat N = Node number
	Sink[1]		Not Applicable	
	Event			
Added to Form Gert IIIQ	Queue			C = Initial number in the queue D = Maximum number allowed in queue N = Node number

Note: [1] The sink node can not really be classified in this manner since it can be an event node with a sink code assigned to it. The symbol shown is the most common form used and is included here as a matter of convenience.

assumed to be of the same type and thus is processed through the model, intact, as a multipallet, pallet, etc. (5) One pallet of unloaded plane cargo is assumed to be of the same type and is processed as an entity. (6) There are three accumulation nodes (36, 38, 81) used to represent cargo buildup until a full load for a plane or truck is stored before the loading operation is initiated. (7) Arrivals are generated by a time distribution. (8) The terminal operation is based upon a 24 hour work day, but can be extended.

Potential bottlenecks of the air cargo terminal operations are shown in Figure 2.1 by means of the isolated nodes: 106, 107, 108, 115, 116, 117, 126, 127, 128, 129, 130, 131, 132, 133, 135, 141, 147, and 149.

The GERTS IIIQ simulation model also has imbedded within it activities which are a direct function of construction specifications. These are: (1) The distance between stations determines the transfer times. Thus either the distance between stations can be reduced, or the speed of transporting cargo increased, (i.e., by employing a faster conveyor or towline.) (2) The waiting area needed to accommodate the service determines the maximum allowable number in a queue node. Since the server can service items only at a specified rate, the number of servers may have to be increased if saturation occurs. Thus additional space and equipment may be needed to accommodate the required arrival and departures to the queue. (3) The height of the building and the storage area permitted determines the travel time distribution of storage equipment, particularly the stacker cranes. The retrieval and storage time on the GERT IIIQ diagram for each type of cargo is directly related to the dimensions of the storage area.

3.0 PARAMETRIC STUDIES

3.1 <u>Data Collection</u>. In order to simulate the material handling operations as performed by the model, it was necessary to develop empirical distributions for the service times, travel times, storage times, and the queueing length allowed for each handling station. The parametric values in Table 3.1 were calculated from construction drawings of the planned air cargo facility at Travis Air Force Base and from the Dortech report on material handling equipment. [1] All of the calculations are summarized in [5].

Service time is defined as the length of time the equipment and/or personnel are available to give service to an item until they are free to give service to another item. The service times used in the simulation were assumed to have a normal distribution.

The transit time is defined as the time it takes an item to move from one part of the system to another. It is assumed that the volumes of cargo moving on each path are independent of means and variances of other activities to that different cargo volume types can be added along the activity branches. The transit times are calculated for the distributed distances between the stations divided by the average speed of the material movement equipment, such as forklifts, conveyors, towlines, and cranes.

Table 3.1
Time Parameters (Hours)

DESCRIPTION	MEAN	MIN.	MAX	STD DEV
GERT Functional Branch	0.0			
Truck Arrival	1.0	.5	3.0	.2
Document Transfer	.25	.1	1.0	.1
Parking	.30	.1	1.0	.1
Truck Unloading	3.0	.5	6.0	.2
Cargo Sort	.2	.1	4.0	1.0
Multipallet & Pallet Transfer (Truck Dock-Storage)	.048	.01	.50	.01
Multipallet & Pallet Transfer (Truck Dock-Plane Dock)	.10	.04	.16	.01
Multipallet & Pallet Transfer (Truck Dock-Pallet Buildup)	.2	.1	2.0	.1
Multipallet Storage-Retrival	.09	.02	.17	.1
Multipallet Transfer (Storage-Plane Dock)	.11	.02	.21	.1
Multipallet & Pallet Transfer (Buildup-Plane Dock)	.16	.02	.3	.1
Cartable Transfer (Truck Dock Stacker)	.16	.12	.21	.1
Cartable Storage-Retrival	.09	.05	1.0	.01
Cartable Transfer (Stacker-Buildup)	.29	.15	.43	.01
Multipallet Transfer (Storage-Buildup)	.75	.50	2.0	.1
Pallet Buildup to Plane Dock Transfer	.09	.02	.16	.01
Oversized Cargo (Storage & Retrieval)	.11	.02	.2	.01
Oversized Transfer (Truck Dock-Buildup)	.02	.01	.5	.01
Special Handling Time	1.7	.5	3.0	.5
Spec. Handling Transfer (Truck Dock-Plane. Dock)	.17	.09	1.0	.1
Unload & Load C-5A	.5	.4	1.0	.1
Unload & Load C-141	.18	.08	.60	.1
Plane Arrival	2.0	1.0	4.0	.5
Recrate Service	.6	.2	1.0	.1
Plane Cargo Checking Time	.2	.01	1.0	.1
Pallet Transfer (Storage-Plane Dock)	.04	.01	1.0	.01
Pallet Storage-Retrieval	.033	.01	1.0	.01
Recrating-Truck Dock Transfer	.10	.1	.21	.1
Recrating-Buildup Transfer	.10	.1	.50	.01
Plane Dock-Plane Dock Transfer	.02	.01	.50	.01
Distributed Cargo Handling	.1	.01	5.0	.01
Inspection, Code, Check,		.01	5.0	.01
Sort	2.5	.01	5.0	.01
Truck Loading Time	3.0	.5	6.0	.2
Cartable Handling Time	3.0	.5	6.0	.2
Priority Unloading Time	3.0	.5	6.0	.2
Pallet Buildup	.75	.01	2.0	.01
Pallet Breakdown	.75	.01	2.0	.01

The maximum number of items allowed in a queue is dictated by the existing structure and floor space. By taking an average arriving cargo item, and the allowable area, the maximum allowable parameter for each queue station can be determined.

The sequence of arrival patterns for airplanes and trucks are taken from the results of observation made by the Dortech report. In the simulation model, the arrival patterns are generated by a pseudo-random Erlang type generator, where it is assumed that the time of the next arrival is independent of the previous arrival.

3.2 Simulation Studies. A series of simulation runs were conducted to determine potential bottlenecks and to evaluate the best construction-oriented strategy that could be taken to eliminate them. First the model was simulated recursively to ascertain average queue values of steady state operations inside the terminal. Then ten simulated one-day operations were run to establish average bottleneck values and to justify the probabilities associated with the activities emanating from the probabilistic nodes. It was found that for twenty plane departures/day, ten simulation runs proved to be adequate. The results of the simulation runs are summarized in Table 3.2 which also lists the bottlenecks that occurred, the queue nodes and branches that were affected, the service time, the maximum number allowed in the queue nodes, and the number of servers per service station.

After the steady state condition of the system was determined, the extremum for each of the three parameters, service time, maximum allowed in a queue, and the number of servers per station was established by holding the other two parameters at their steady state values. Using the extremum as a basis, the number of servers parameter was held at a chosen value while the other two parameters were varied until a bottleneck free operation per that activity was obtained. By repeating the procedure, a curve delineating where bottlenecks will or will not occur can be obtained for each bottleneck area.

This procedure is continued until a family of equidistant curves convering all combinations of the three parameters is generated for all the bottleneck areas.

Several preliminary runs were needed to validate the model. Under the proposed system by Dortech, the twenty plane departures considered normal for a twenty-four hour operation at Travis Air Force Base was employed throughout the simulation studies. Using the proposed number of stations per activity, the operation time under bottleneck free condition was very close to twenty-four hours of simulated time. The validation considers also the average use of each department by noting the average busy time of the service queues. Within the limits of the model structure, the storage capacity was less than 20% filled when the steady state was obtained. The results as a whole revealed that the model was a favorable representation of the true environment of the material handling operations of a Dortech air cargo terminal.

In the simulation analysis, only the critical bottleneck areas were studied for average system performance and the elimination of

items balking to the bottleneck indicators. It was assumed that the bottleneck areas that were analyzed were buffered enough from each other so that the changing of the parametric values of one activity would be relatively independent from another queue. Zero items in the bottleneck indicators is the final criteria for a good point.

3.3 Simulation Results. Results of the simulation runs are shown in Figures 3.1 through 3.5. For these cases it can be seen that an increase in the maximum number allowed in a queue is directly proportional to the increase in the service time for handling an item. The latter condition prevails until an average system performance value is reached, and for which the maximum allowable in a queue is relatively constant over an increase in the service time per item. That is, the system has reached its steady state condition where arriving items into the queue equals the departing items from the queue node. For this case, there would be no items balking to the bottleneck indicators. By steadily increasing the service time to handle an item beyond that somewhat steady state of the system, the maximum number of items allowed in the service queue must now be increased to permit more waiting items to be serviced. As can be seen from curves, increases in the maximum number allowed in a queue becomes directly proportional to the increased service time per item.

The significance of the bottleneck curves and the simulation output statistics can be correlated to construction concepts. In general, for a given type of handling equipment, the cost is reduced if either the distance is reduced or the loads moved/unit time is increased. Therefore, a designer should seek to find a combination of locations, handling equipment and capacity/unit time to satisfy these criteria. When two out of three critical parameters are known, the third constraint can be ascertained from the graphs. For example, because of the restrictive waiting area and the prohibitive cost of handling equipment required per server, the service time must be adjusted accordingly to assure that with existing system performance, no items will balk to the bottleneck indicators. The curve to be used is determined from the number of servers per activity parameter. Once the number of servers has been selected, the combination of the other two parameters must either be below or on the respective curves in order to guarantee bottleneck free operation of that activity. Otherwise, any point chosen above the respective curve has a high probability of creating a bottleneck area for that activity.

The simulation at steady state showed the bottlenecks in Table 3.2 to be system bottlenecks in the model with the proposed Dortech design. Accordingly the following are the bottleneck areas: node 147 is the cartable truck loading dock; node 133 is the pallet breakdown station; node 128 is the priority handling service; node 117 is the pallet buildup station; node 115 is the cartable handling truck docks.

Comparison between the original and the final model design revealed that bottleneck areas were eliminated the easiest by increasing the number of servers per bottleneck station. The results can be seen in Table 3.3, where the service time and the maximum number of items allowable in the queue are very close to the original estimates as shown in Table 3.2.

Another aspect uncovered by the simulation was the sensitivity of manpower loading or the number of servers to an efficient system operation. It was found that by increasing the number of servers, the average system performance tended to be located at a smaller maximum allowable item in a queue parameter and the service time parameter required for the service could be increased. Therefore, a designer having estimated the required working area for a server, the waiting area in front of the queue required, and the desired service time can make a decision on his estimated parameters on which should be decreased or increased, to arrive at the average system performance of that service node as shown in the bottleneck graphs.

Bottleneck Indicator	147	133	128	117	115
Queue Nodes Affected	83-88	75,162, 164	32	23,91	16,17
Branches Affected	83-89 85-89 88-89	164-76	32-33	91-24	17-18
Initial Parameters Service Time (Hrs) Max. # Allowed No. of Servers	 3.0 5 2	 .75 9 3	 3.0 4 1	 .75 150 2	 3.0 6 2

TABLE 3.2 BOTTLENECKS WITH ORIGINAL PARAMETERS

Bottlenecks eliminated at the average system performance value		Bottleneck Nodes				
		83	164	32	91	17
Initial # of Servers	Service Time	2.0	.6	2.9	.6	2.8
	Max. # Allowed	8	13	8	250	8
	No. of Servers	2	3	1	2	2
Increased # of Servers	Service Time	3.1	.7	2.5	.7	3.0
	Max. # Allowed	7	4	2	120	4
	No. of Servers	4	4	2	6	3

TABLE 3.3 BOTTLENECK FREE OPERATION

Event	Node	Original Processing Time	Processing Time with Initial # of Servers	Processing Time with Increased # of Servers
Plane Depart.	45	30.6 (Hrs)	33.27	18.3
Pallet Unload.	48	3.19	3.07	3.15
Priority Unl.	33	7.27	6.97	3.86
Noncart. Unl.	27	6.07	6.02	6.31
Cartable Unl.	18	6.13	5.92	3.70
Multipla. Unl.	8	3.12	3.17	3.09

TABLE 3.4 AVERAGE SAMPLE PROCESSING WITH BOTTLENECK FREE OPERATION

Queue Node	Original Design	Initial # of Servers	Increased # of Servers
17	2.16	2.75	1.13
32	1.68	1.38	.76
83	3.45	3.68	2.75
91	142.00	160.00	102.50
164	2.7	1.38	1.56

TABLE 3.5 AVERAGE NUMBER OF ITEMS IN QUEUE

Queue Node	Original Design	Initial # of Servers	Increased # of Servers
17	1.0	.99	.80
32	.87	.89	.86
83	.89	.90	.82
91	1.0	1.0	1.0
164	.75	.73	.78

TABLE 3.6 AVERAGE BUSY TIME OF QUEUE

When considering the alternatives for each bottleneck area, the overall throughput of the system must be considered in the choices of parameters. It is observed in Table 3.4 that increasing the maximum allowed in a queue did not influence the processing time of the material handling operation of the terminal. In fact, it added more waiting items in the bottleneck queue node and consequently increased the average number of items in the queue as shown in Table 3.5. On the other hand, there was only a small influence in the throughput by increasing the number of servers per activity because the number of items processed per unit time were increased. However, the average busy time of the queue as shown in Table 3.6 was still the same. The most important influence upon the throughput of the system was the reduction in the service time for handling an item, because of the fact that the faster one serves an item, the faster the item can enter and leave the system. Therefore, it is suggested that when certain constraints are given, the first design parameter that should be chosen is the storage area required in front of a service queue, because this is where most potential bottlenecks are caused and is the hardest item to adjust because of the limited dimensions of the existing terminal building. The value to be chosen can be determined from the average system performance for that activity. This value is indicated on the curve from the simulation by the constant variation of the maximum allowed in a queue parameter.

The network model and the resulting bottleneck analysis may be used to assist the designer in selecting succeeding alternatives for which to develop activity data summaries and related system cost estimates. However, the above procedure will not necessarily result in an optimum system design of an air cargo terminal, but it provides an orderly method for selection and evaluation of alternative systems and probably increase the likelihood of approaching the optimum system. Furthermore, since selection of the next alternative system to consider is based upon a path whose priority has been established by the volume to be handled which was determined from the critical bottleneck areas in our simulation runs. Thus, the number of alternatives to be considered in detail is significantly reduced.

4.0 CONCLUSIONS

No single technique is likely to provide a final design for an air cargo terminal facility directly. But the network analysis of the materials handling operation of an air cargo terminal has provided a framework for analysis, the results of which can assist the designer in finalizing his recommendation.

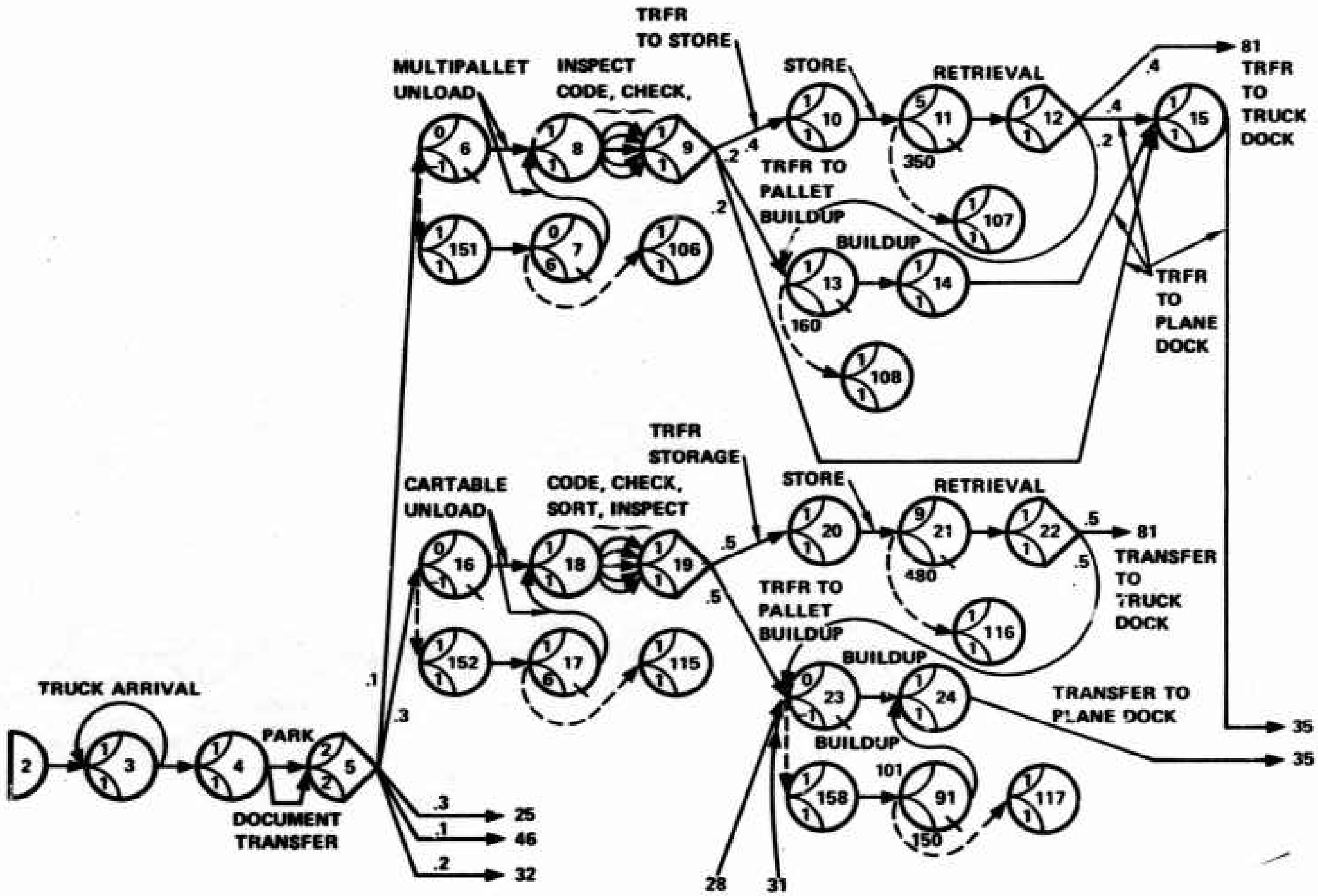


Figure 2.1 GERTS III Q Simulation Model of an Air Cargo Facility.

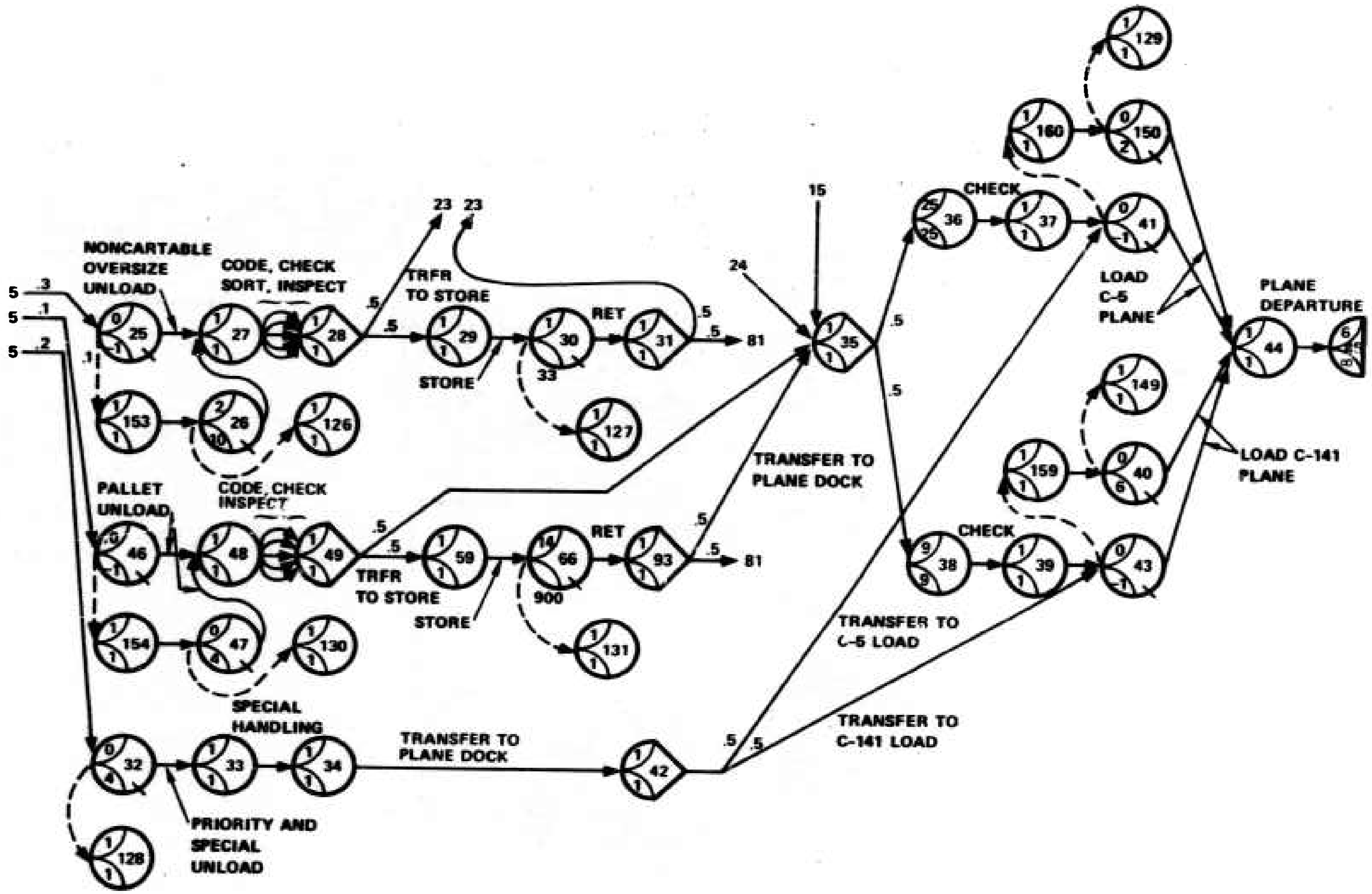


Figure 2.1 (Continued)

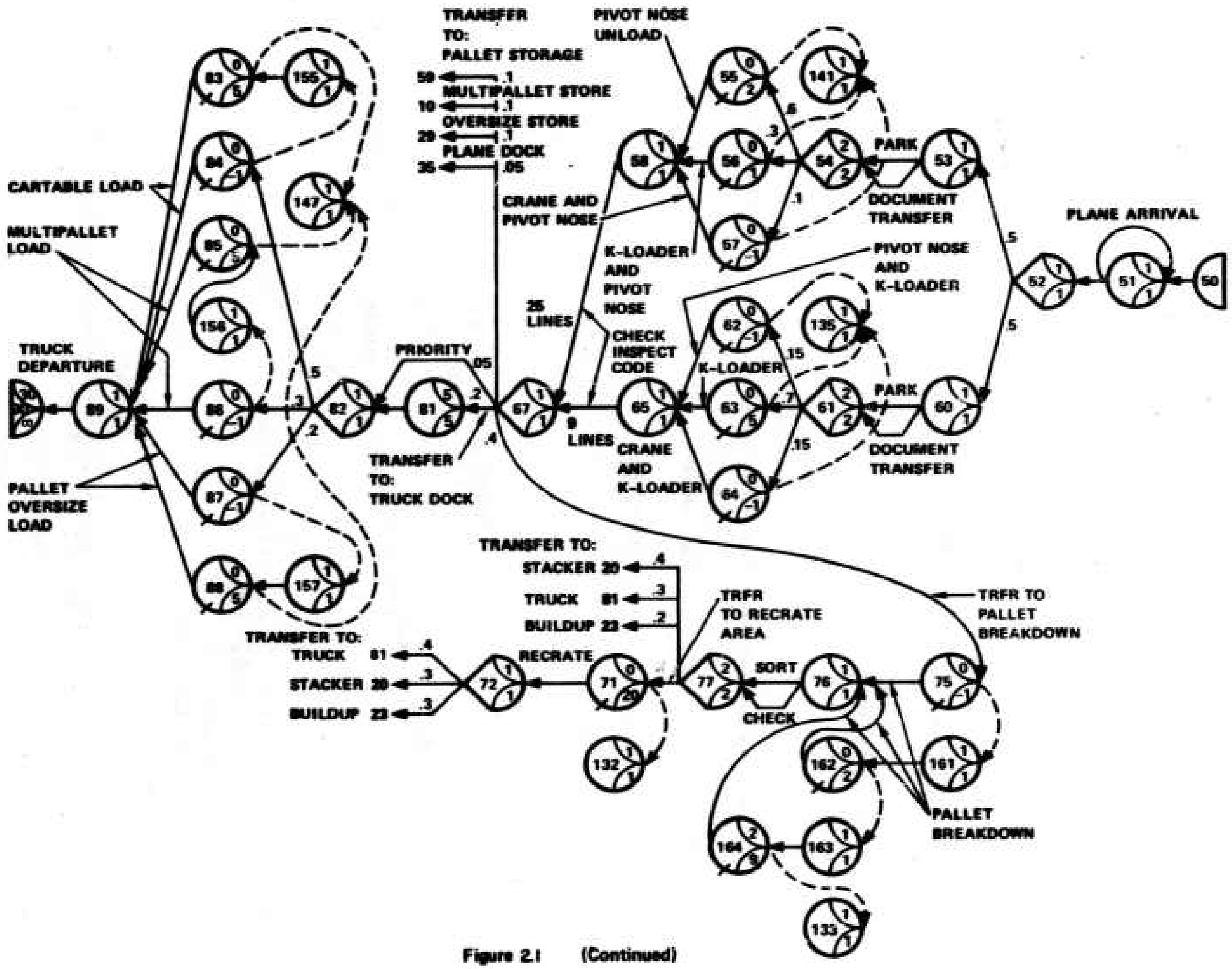


Figure 2.1 (Continued)

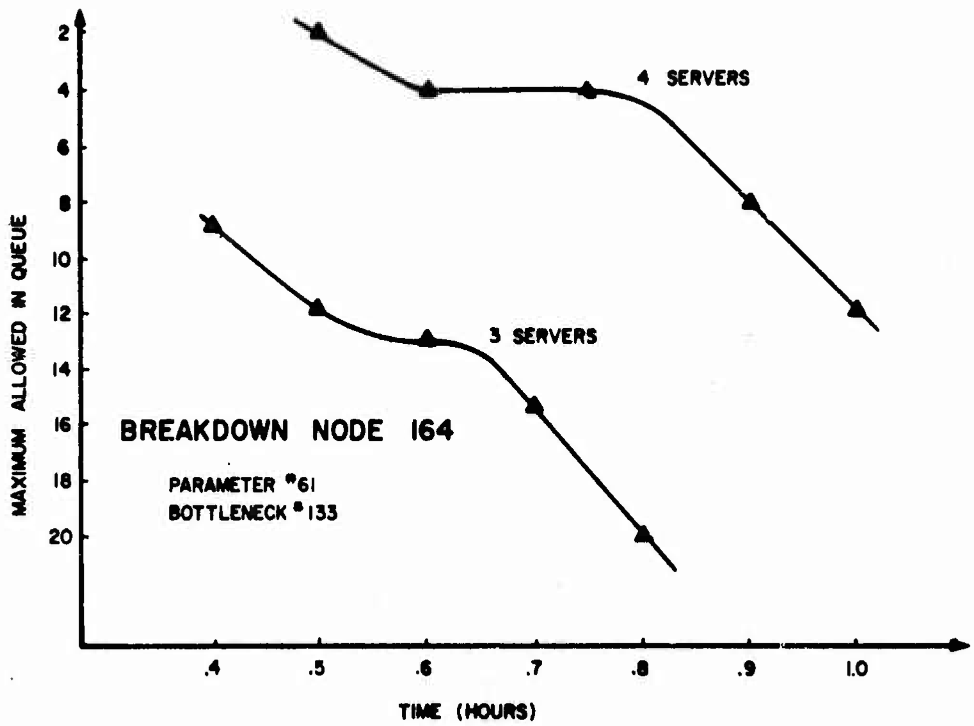


Figure 3.1

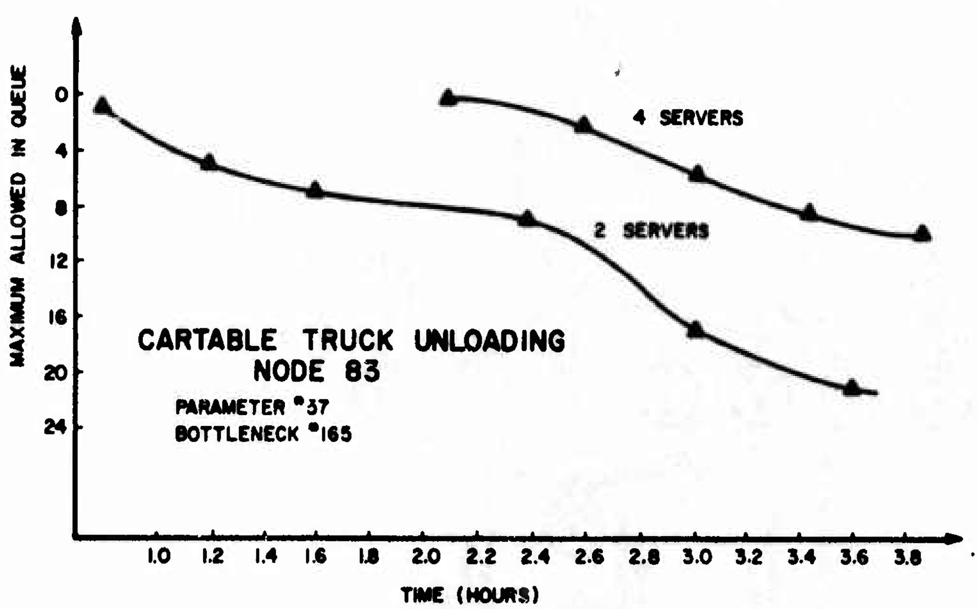


Figure 3.2

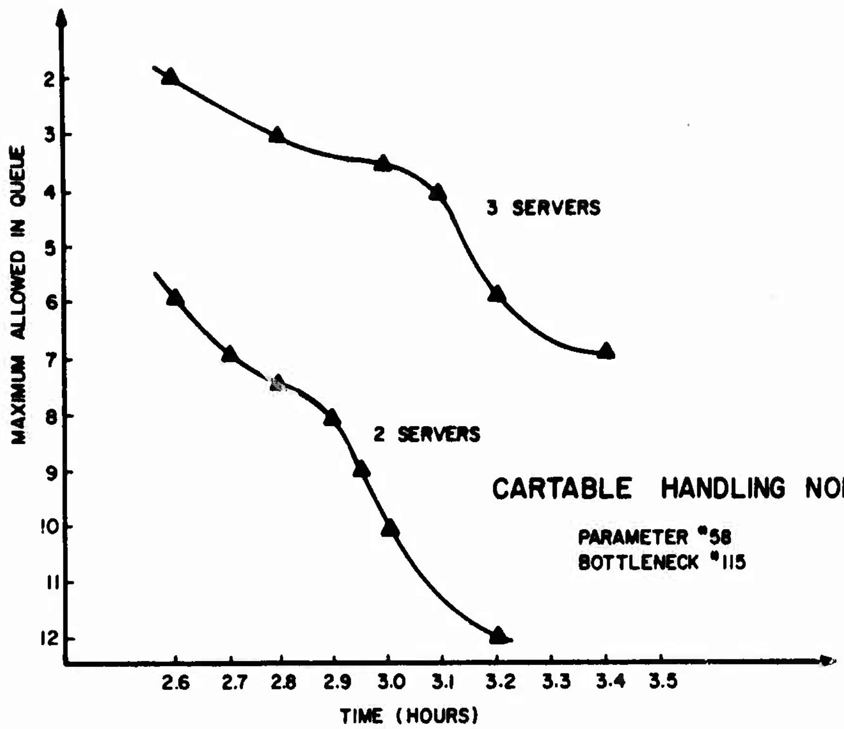


Figure 3.3

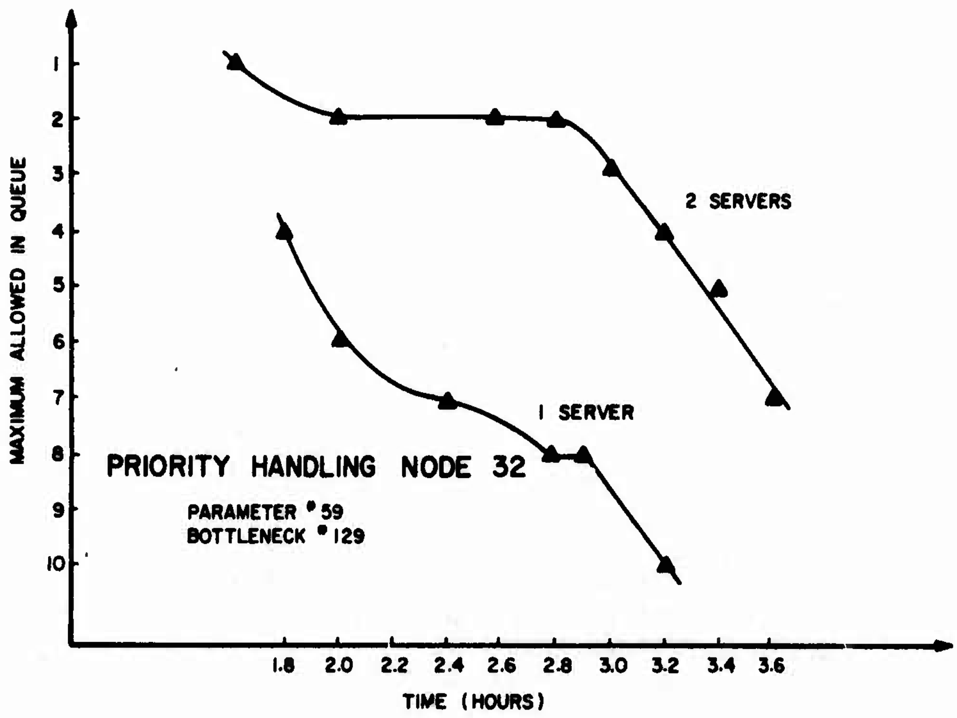


Figure 3.4

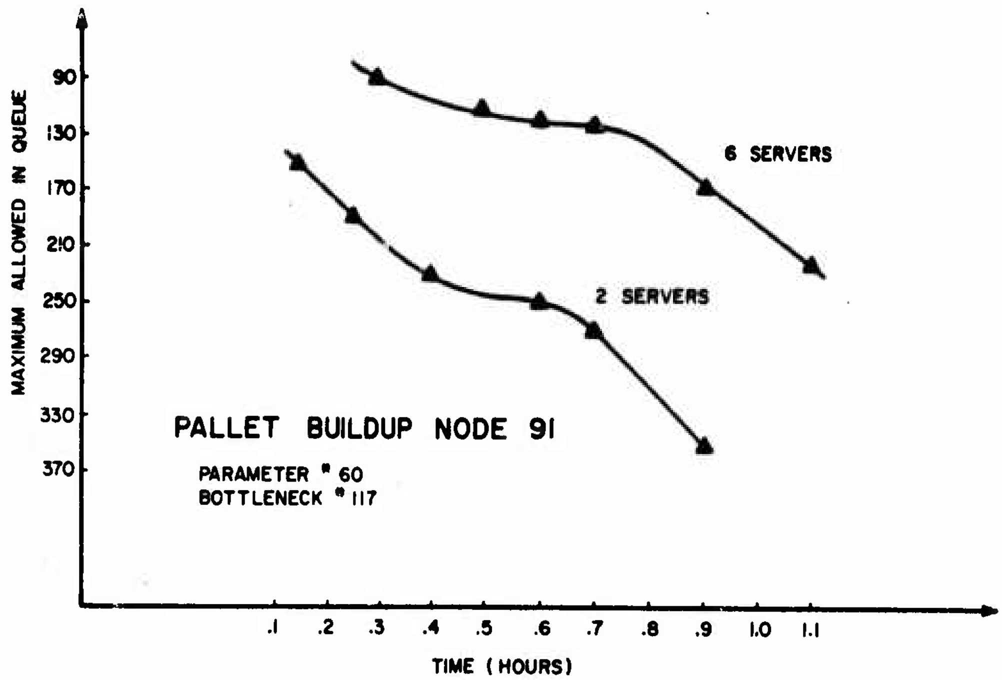


Figure 3.5

REFERENCES

1. Air Freight Terminal Complex: Architect-Engineer Definitive Report, Prepared by Dortech, Stamford, Conn., Contract No. F11623-68-C-0411, for Scott Air Force Base, 1968.
2. Porte, H. A. and Happ, W. W., "Activity Networks to Model Transportation Systems Subject To Facility Constraints," Ninth Annual Allerton Conference on Circuit and System Theory, pp. 1151-1160, October 1971.
3. Lee, C. and McNamee, L. P., "A Stochastic Network Model For Air Cargo Terminals," Ninth Annual Allerton Conference on Circuit and System Theory, pp. 1140-1150, October 1971.
4. Pritsker, A.A.B., Burgess, R. R., "The GERT Simulation Programs: GERTS III, GERTS IIIQ, GERTS IIIC, and GERTS IIIR", NASA/ERC Contract NAS-12-2113, Virginia Polytechnic Institute, Department of Industrial Engineering, 1970.
5. Lee, Chao, "Parametric Studies of an Air Cargo Terminal", M.S. Thesis, School of Engineering and Applied Science, UCLA, March, 1972.